Measuring CEvNS with Ge

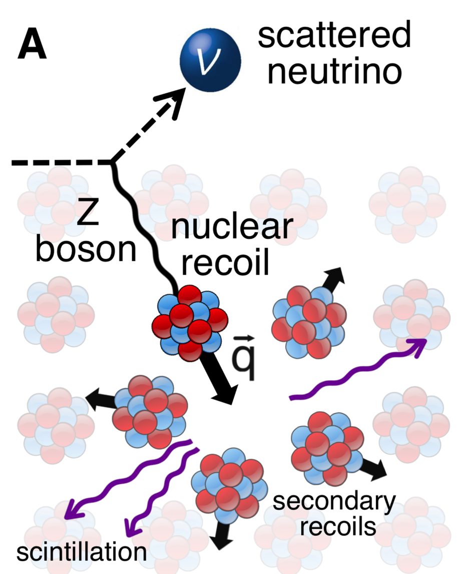
NC STATE UNIVERSITY

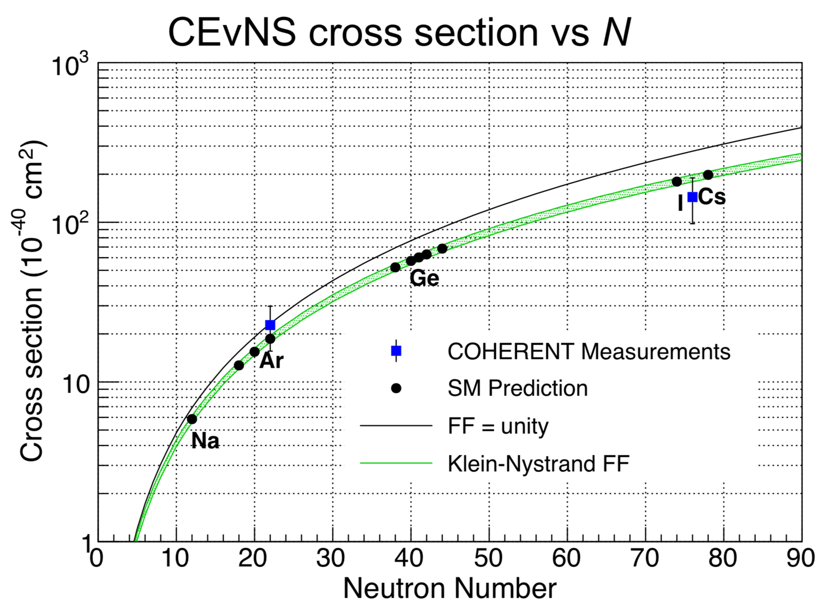
Contribution ID# 553

Keith Mann on behalf of the COHERENT collaboration
North Carolina State University
Raleigh, NC

What is CEvNS?

CEvNS, or Coherent Elastic Neutrino Nucleus Scattering, is a neutral current process that occurs when a neutrino, mediated by the Z boson, elastically scatters off of the target nucleus as a whole, instead of individual nucleons. A portion of the incident neutrino's momentum is transferred to the nucleus.





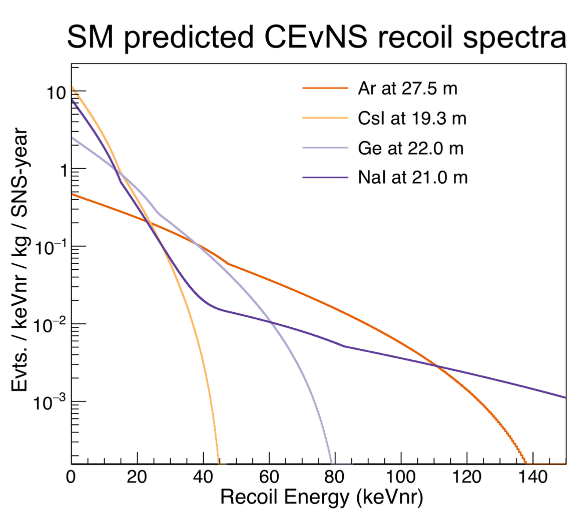
Above Left: When a neutrino's wavelength is sufficiently large, it will scatter off of the nucleus as a whole, imparting some of its momentum to the nucleus in the process. This is a neutral current process; consequently, the interaction is mediated by the Z boson.

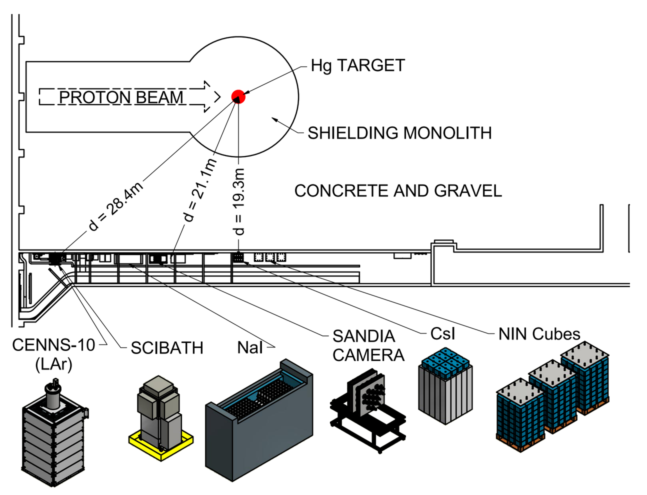
Above Right: N^2 dependence of the CEvNS cross section. Four detectors of varying atomic masses are in the process of being deployed; each black dot represents the theoretical CEvNS cross section, while the blue squares with error bars depict the measured CEvNS cross section value, measured by the CsI and LAr detectors.

It was predicted as part of the standard model in 1974[1,2], and first observed by the COHERENT collaboration in 2017[3]. Event though the cross section of this interaction is fairly large, detection is difficult because the energy transferred to the nucleus is rather small; measurements require detectors with exceedingly low energy thresholds and low backgrounds.

COHERENT collaboration

The COHERENT collaboration is a multi-institutional effort geared towards the measurement of CEvNS. In order to test the N^2 dependence of the CEvNS cross section, several detector assemblies with differing atomic masses are in various stages of deployment in the basement of the Spallation Neutron Source (SNS) at ORNL. In addition, supplementary detectors have been put in place to better understand and measure backgrounds that compete with the CEvNS signal. So far, coherent scattering has been observed in CsI.





Left: Estimated recoil spectra from CEvNS events.

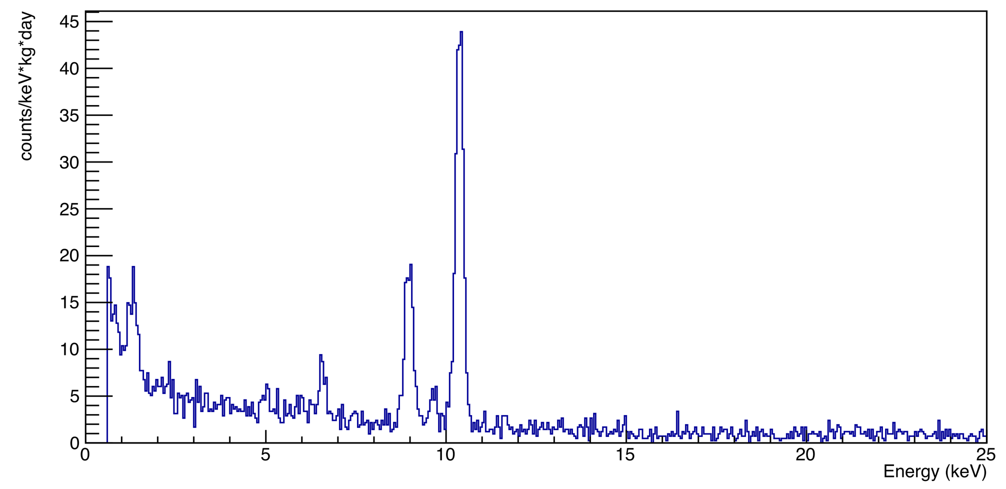
Right: Schematic of the hallway in the SNS basement showing the relative positioning of the different detector systems within the COHERENT collaboration.

One of the advantages of using the SNS as a neutrino source is because a pulsed beam is used. By using the timing of these pulses, we can discriminate against a large portion of steady-state backgrounds.

Why Germanium?

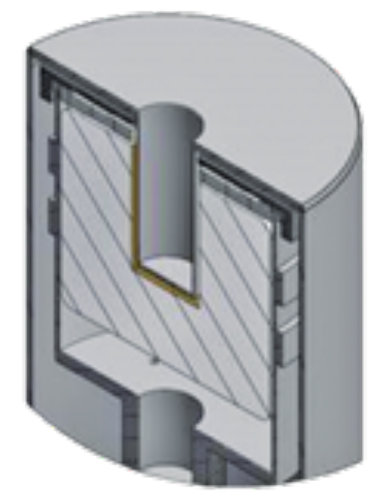
A P-type point-contact germanium detector is a strong candidate for detecting CEvNS events.

- Low Noise: The noise level of a detector depends in part on the capacitance of the contact. Having a point contact reduces the contact surface area, thereby reducing its capacitance.
- High Energy Resolution: Ge is a semiconductor, which means that it has a small ionization energy (~3eV).



Left: Native backgrounds (from the Ge, coldfinger, and dewar) present within the < 25keV energy range, measured in the Malbek Dark Matter detector. Image Credit: Adapted from https://arxiv.org/pdf/1407.2238.pdf

Below: Schematic cross section of a ppc Ge detector. Image Credit: Canberra / Mirion Technologies



Because of these attributes, we can investigate:

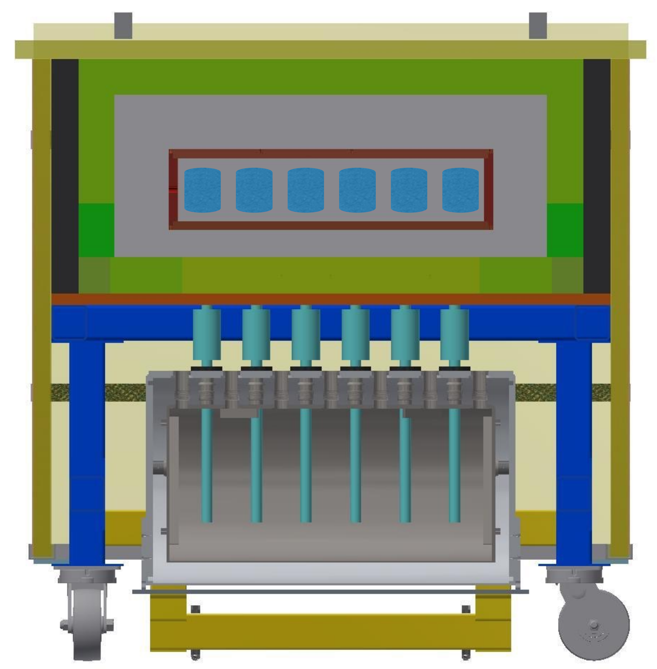
- Weak Mixing Angle
- Non-Standard Interactions (NSI)
- Neutrino Magnetic Moment
- Nuclear Form Factor

Detector Design & Deployment

An array of low-threshold (noise <150eV FWHM), large mass (>2kg each) ppc detectors are in the process of being deployed at the SNS to measure CEvNS:

One of the primary hurdles to overcome in measuring CEvNS events is a sufficient reduction in background. To do this, COHERENT has implemented multiple layers of shielding for the Ge detector array. Starting from the outermost layer and going inwards there are five levels of shielding:

- Plastic Scintillator: Outer layer of plastic scintillator will be used to veto incident muons.
- Lead: Attenuates gammas from steady state background sources.
- Polyethylene: Moderates neutrino-induced neutrons (NINs) generated inside of the lead shielding.
- Copper: To reduce Bremsstrahlung radiation.
- Additional Poly: Placed between the detectors for further neutron moderation and background reduction.

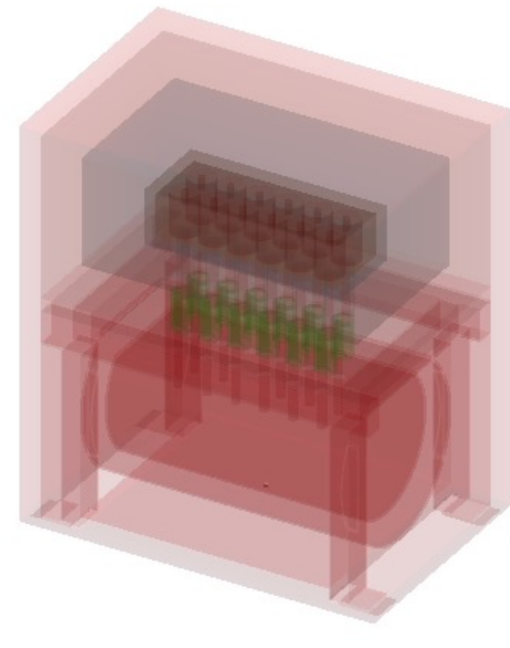


Above: Schematic cross section of the planned Ge detector array and shielding assembly.

Deployment Timeline

- Detector deliveries Jul 2020 - ~Feb 2021
- Characterization and DAQ commissioning in parallel with deliveries
- Shielding design nearing completion. Fabrication and approvals this summer. Assembly at ORNL in fall/winter.
- Commissioning / data taking by summer 2021.

Signal & Background Simulations

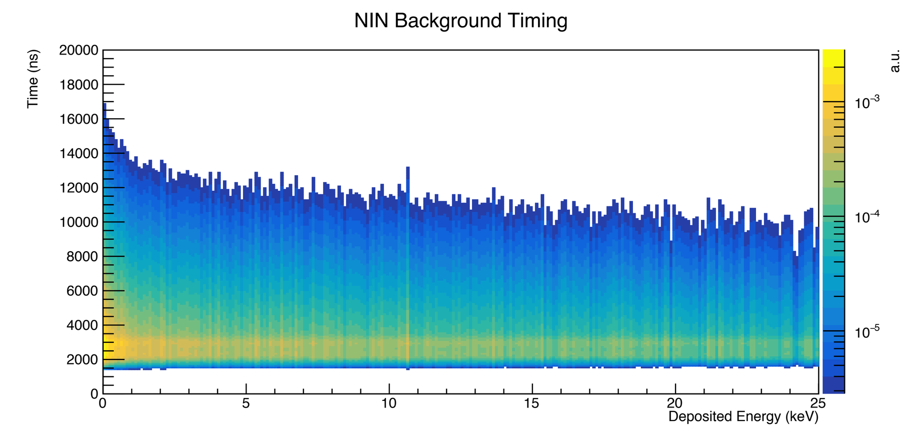


Above: A rendering of the virtual detector that was used in g4simple to simulate expected backgrounds.

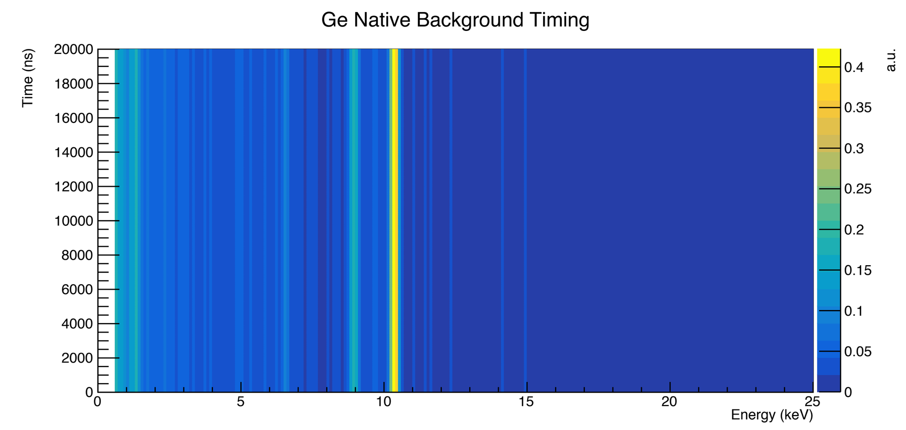
To inform the R&D of the Ge shielding design, g4simple (a lightweight geant4 implementation developed at the University of Washington) was used to simulate several different types of backgrounds. Among these were:

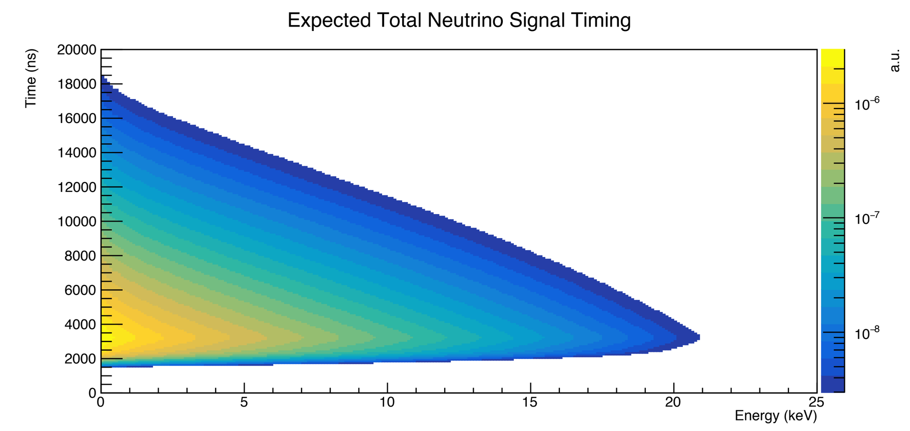
- ^{40}K & ^{208}Tl: Environmental background (such as the walls, floor, etc.)
- 511keV Gammas: From hot-off gas pipe passing through experiment area.
- Neutrino-Induced Neutrons (NINs): Generated within Pb.
- Internal Backgrounds: Steady-state backgrounds originating in the detector cryostat.

One of the advantages of using the SNS as a neutrino source is because a pulsed beam is used. By using the timing of these pulses, we can discriminate a large portion of steady-state backgrounds.
Since NINs are dependent on the timing of the neutrinos originating from the SNS target, as well as the charge drift time within the Ge, a steady-state NIN background was generated and subsequently convolved with the combined timing of the neutrino generation and detector drift time.



Simulations are still underway for calculating the estimated sensitivity for CEvNS in Ge. These simulations will refine the previous estimations, shown in the two figures in the bottom of this section.

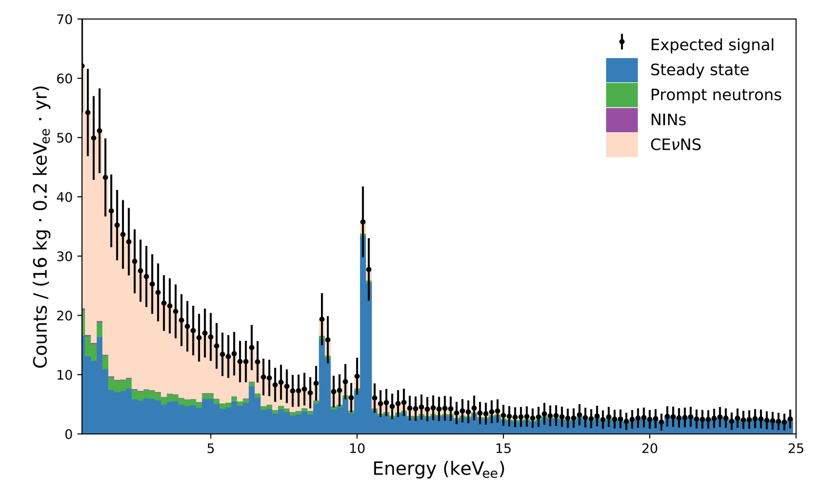




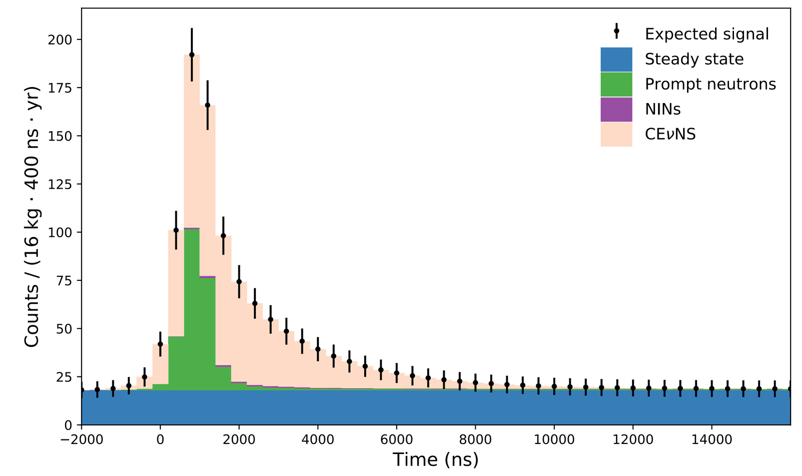
Above Left: 2D Energy/Time spectrum of the NIN background.

Above: Malbek spectrum depicted as an 2D Energy/Time spectrum.

Left: Expected neutrino signal timing, generated using dukecevns.



Above: Expected Ge sensitivity to CEvNS detection with respect to energy. Error bars depict statistical error.



Above: Expected timing distribution of cevns signals and backgrounds.

Acknowledgements

COHERENT is grateful for support from the DOE, NP, HEP, NSF, NNSA, CNEC, and the ORNL staff.

References

[1] *D.Z. Freedman, Phys. Rev. D9 (1974)*
[2] *V.B. Kopeliovich and L.L. Frankfurt, ZhETF Pis. Red. 19 (1974)*
[3] *D. Akimov et al. (COHERENT). Science 357,1123-1126 (2017)*

CNEC Consortium for Nonproliferation Enabling Capabilities

National Nuclear Security Administration